X-48B Flight Research – Test Progress and Instrumentation Needs for the Future

Tim Risch, Gary Cosentino, and Chris Regan

NASA Dryden Flight Research Center, Edwards, CA 93523

Michael Kisska and Norman Princen

Boeing Phantom Works, Huntington Beach, CA 92647

ITEA 13th Annual Test

Instrumentation Workshop

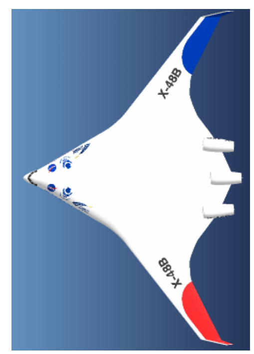
Ridgecrest, California

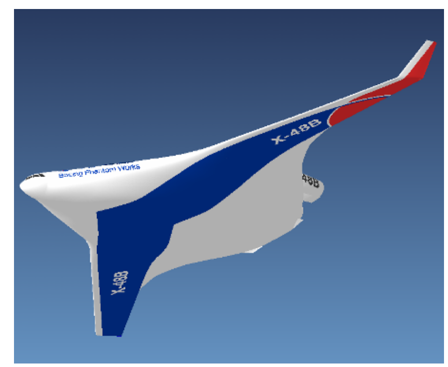
Program Objectives

- Assess stability & control characteristics of a BWB class vehicle in free-flight conditions:
  - Assess dynamic interaction of control surfaces
  - Assess control requirements to accommodate asymmetric thrust
  - Assess stability and controllability about each axis at a range of flight conditions
- Assess flight control algorithms designed to provide desired flight characteristics:
  - Assess control surface allocation and blending
  - Assess edge of envelope protection schemes
  - Assess takeoff and landing characteristics
  - Test experimental control laws and control design methods
- Evaluate prediction and test methods for BWB class vehicles:
  - Correlate flight measurements with ground-based predictions and measurements

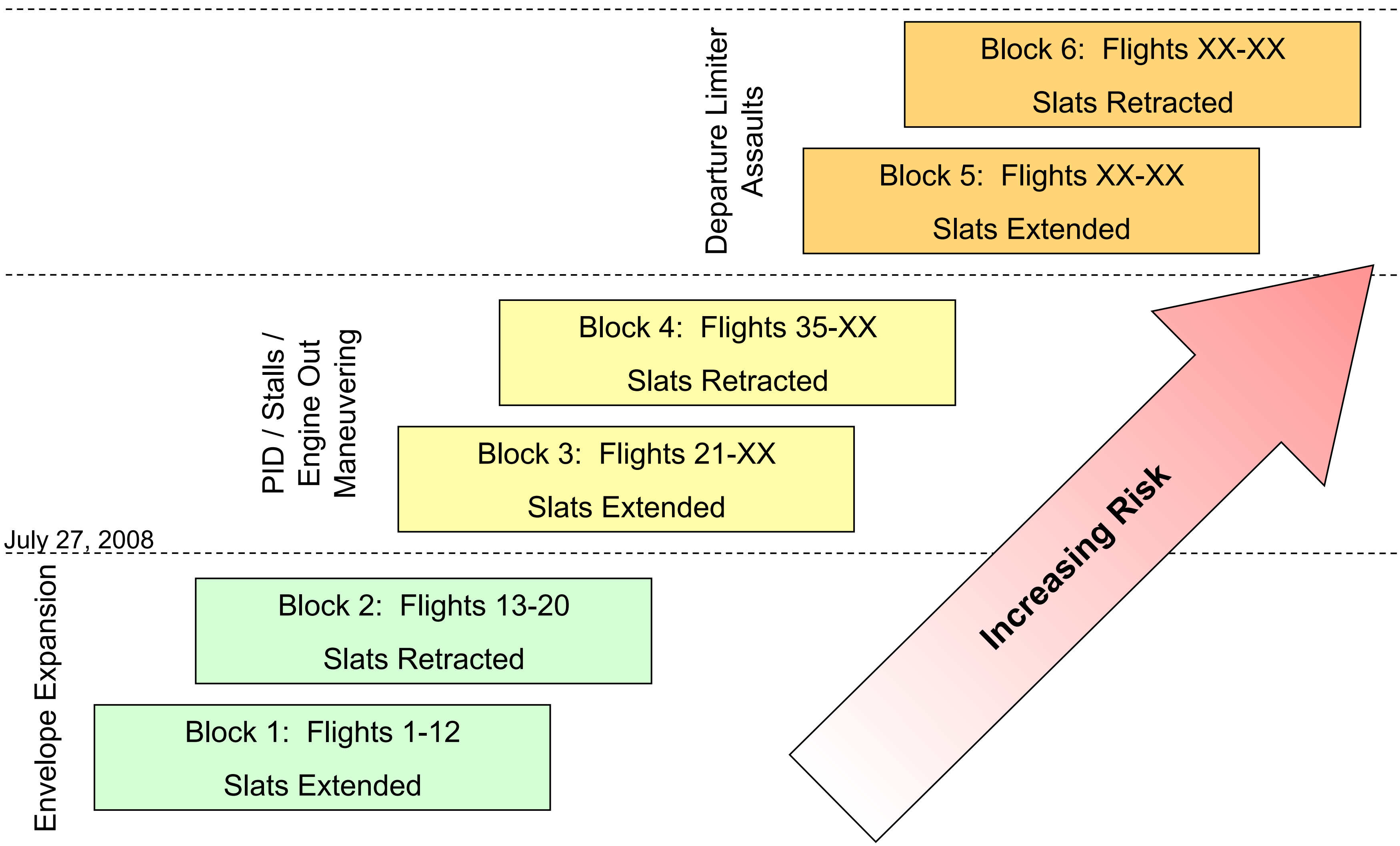
X-48B Flight Research Program

- Flight research provides:
  - Flight Control System risk reduction
  - Required to ensure BWB configuration is as safe as a conventional airplane
- Investigate:
  - Stall Characteristics
  - Departure Onset Boundaries
  - Asymmetric Thrust Control
  - Flight Control Algorithms
  - Envelope Protection Schemes
  - Dynamic Ground Effects
  - Control Surface Hinge Moments





Definition of Test Flight Blocks

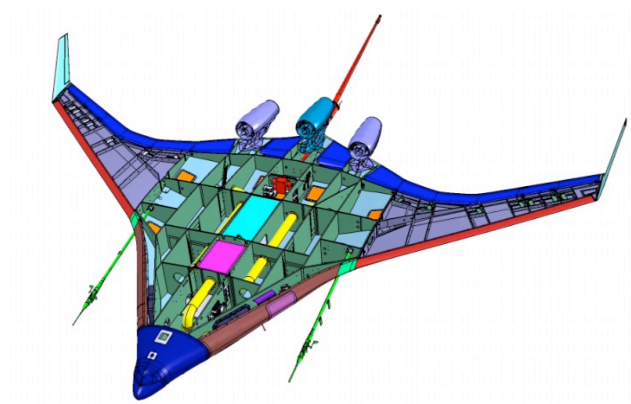


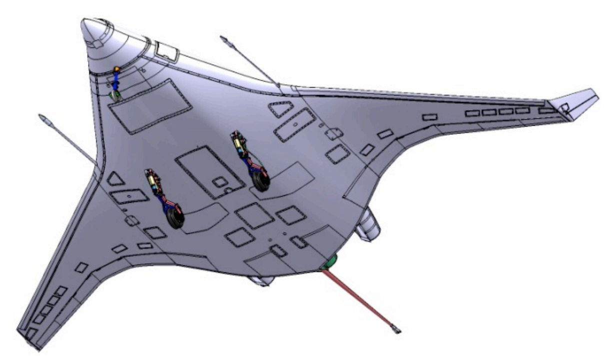
Major Program Accomplishments

- 50 successful flights including 2 flights in 1 day several times
- Completion of envelope expansion phases in both slats extended and slats retracted configurations
- Aircraft capable of operating from hard surface and lakebed runways at Dryden
- Both Boeing and NASA pilots trained to fly aircraft and first NASA pilot mission flown on 8/13/08
- High quality data for various maneuvers recorded and archived for future use
- Preliminary data analysis ongoing with quick look data report for first 20 flights available early 2009
- Ten high AOA flights (near stall) performed in slats extended configuration and stable AOA limits found
- Multiple versions of software upgrades performed resulting in stable test platform
- Takeoffs, landings, low approaches, and go-arounds are routine operations

X-48B BWB Low Speed Vehicle

- Two X-48B Aircraft and Ground Control Station (GCS)
  - Research Partnership of Boeing, NASA, and AFRL
  - Design and fabrication contracted to Cranfield Aerospace
- Air Vehicle Highlights:
  - Dynamically Scaled
  - Uninhabited Air Vehicle
    - Flown by Pilot from Ground Station
  - Powered by 3 Small Turbojets
    - ~52 lbs. of Thrust Each
  - Conventional takeoff and landing
    - Non-retractable Tricycle Gear
    - Slats are Fixed for either Extended or Retra
  - Recovery System
    - Drogue, Parachute, and Air Bags

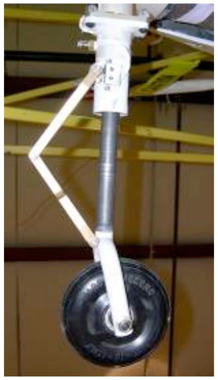




X-48B Vehicle

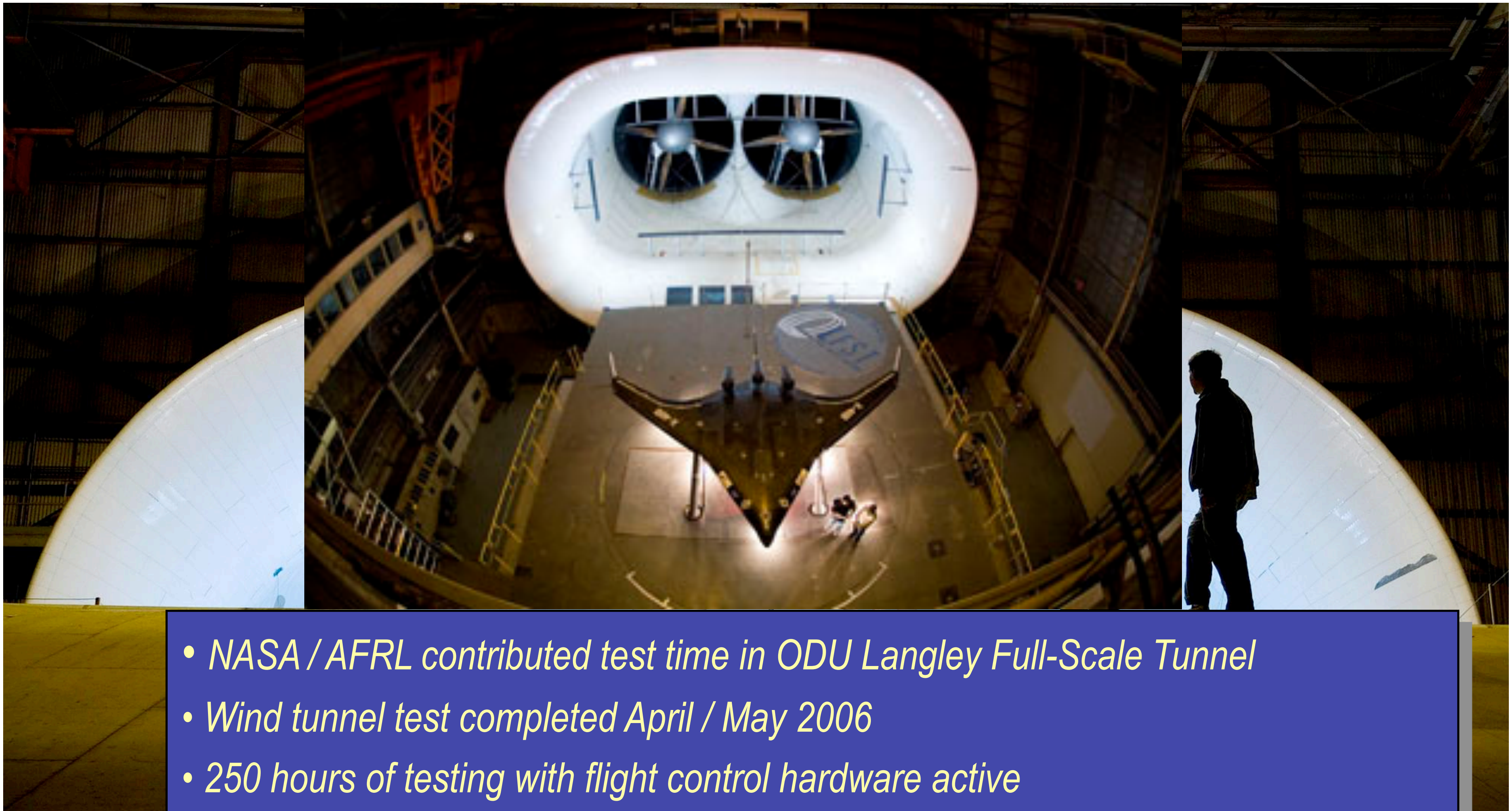
- Design Approach
  - Use low cost (COTS) equipment where possible
    - Engines - JetCat P-200
    - Landing Gear - mountain bike shocks & brakes
  - Use normal industry practice for electronic equipment
  - Use aircraft spec equipment where necessary
    - Radios, IMU, Actuators, Flight Termination System (FTS) parts
  - Save weight to meet dynamic scaling requirements

JetCat P200 Engines



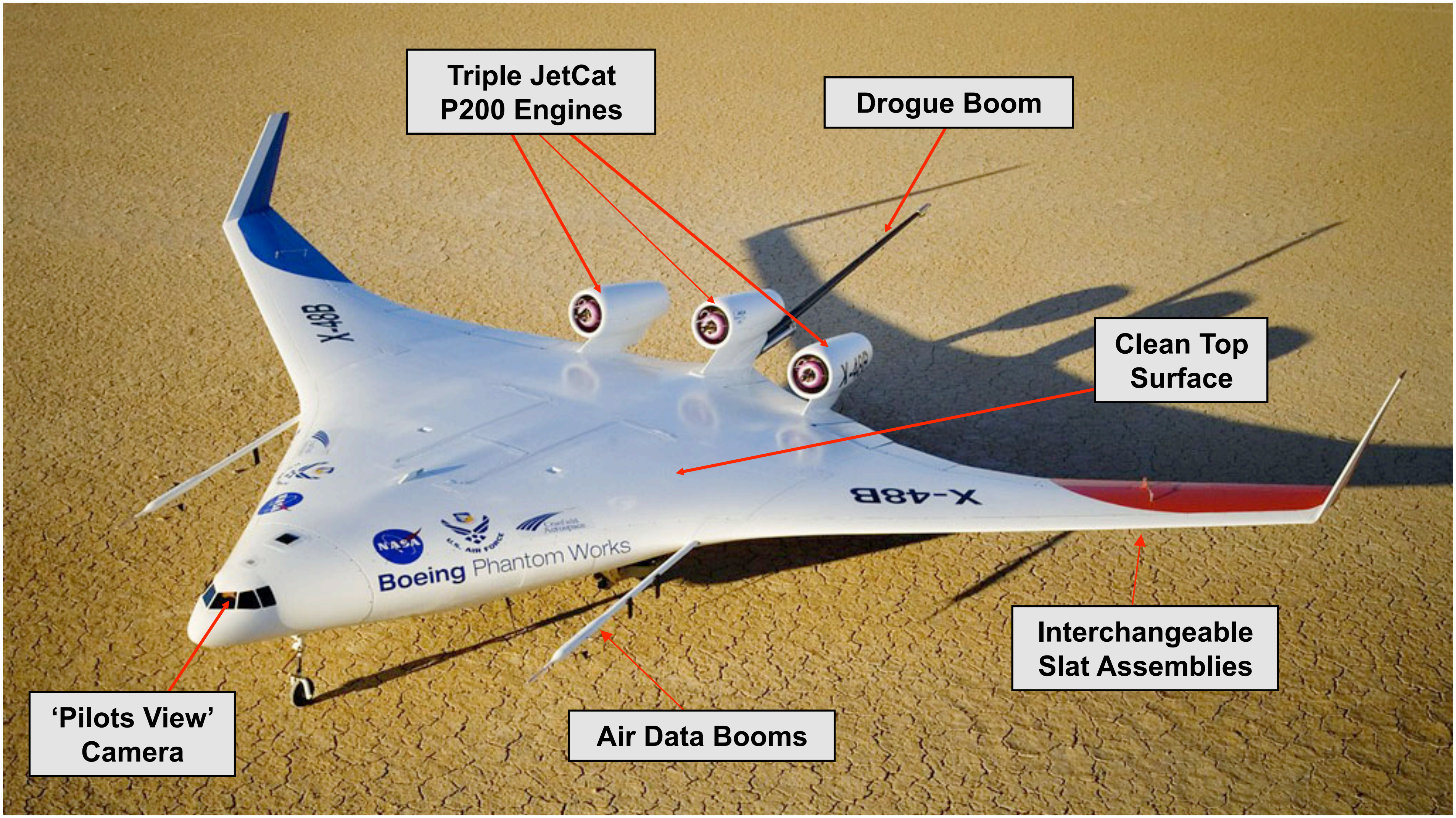
Nose & Main Landing Gear

X-48B 30x60 Wind Tunnel Test

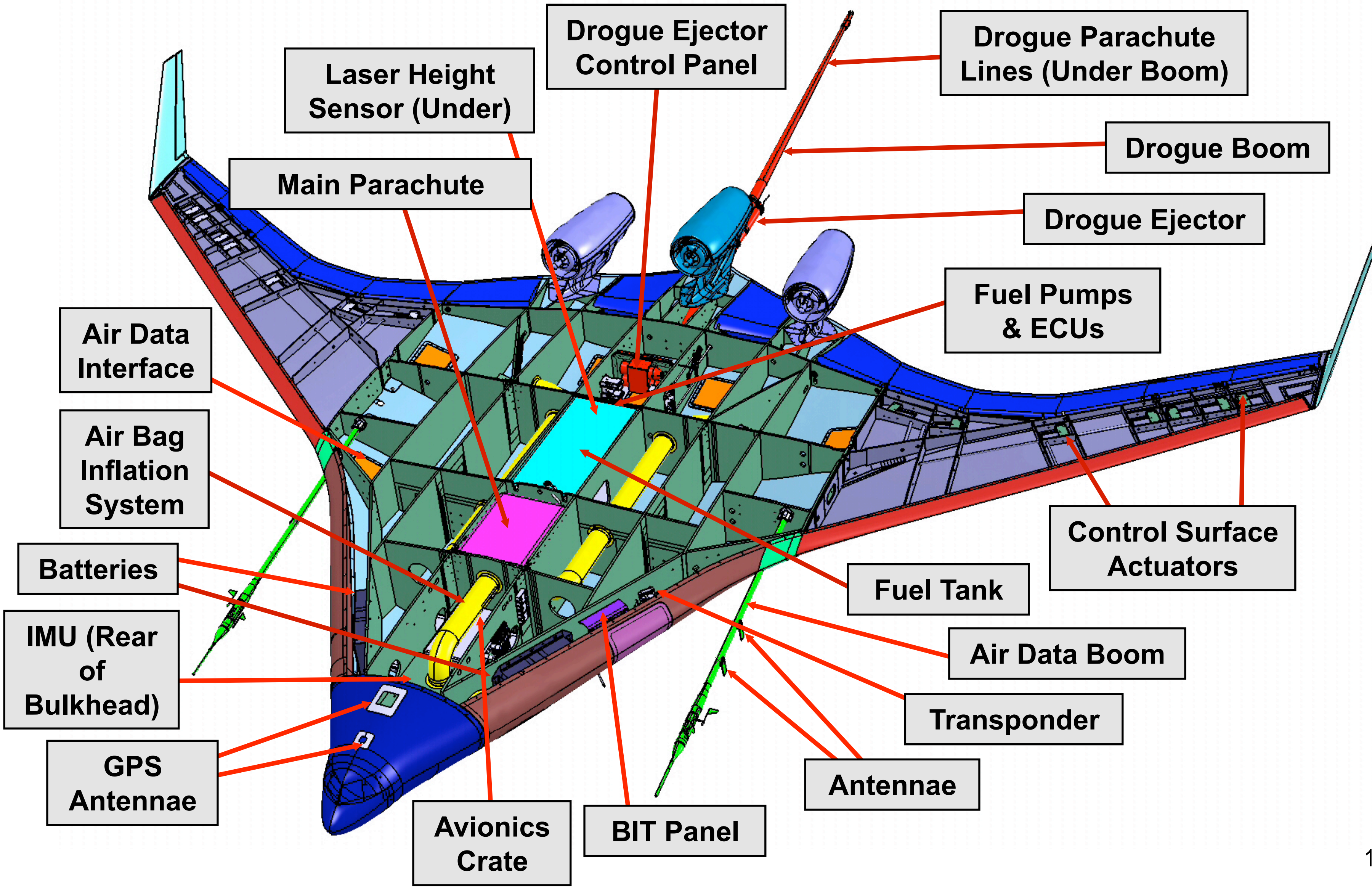


- NASA / AFRL contributed test time in ODU Langley Full-Scale Tunnel
- Wind tunnel test completed April / May 2006
- 250 hours of testing with flight control hardware active
- Data used by Boeing for X-48B simulation and flight control software

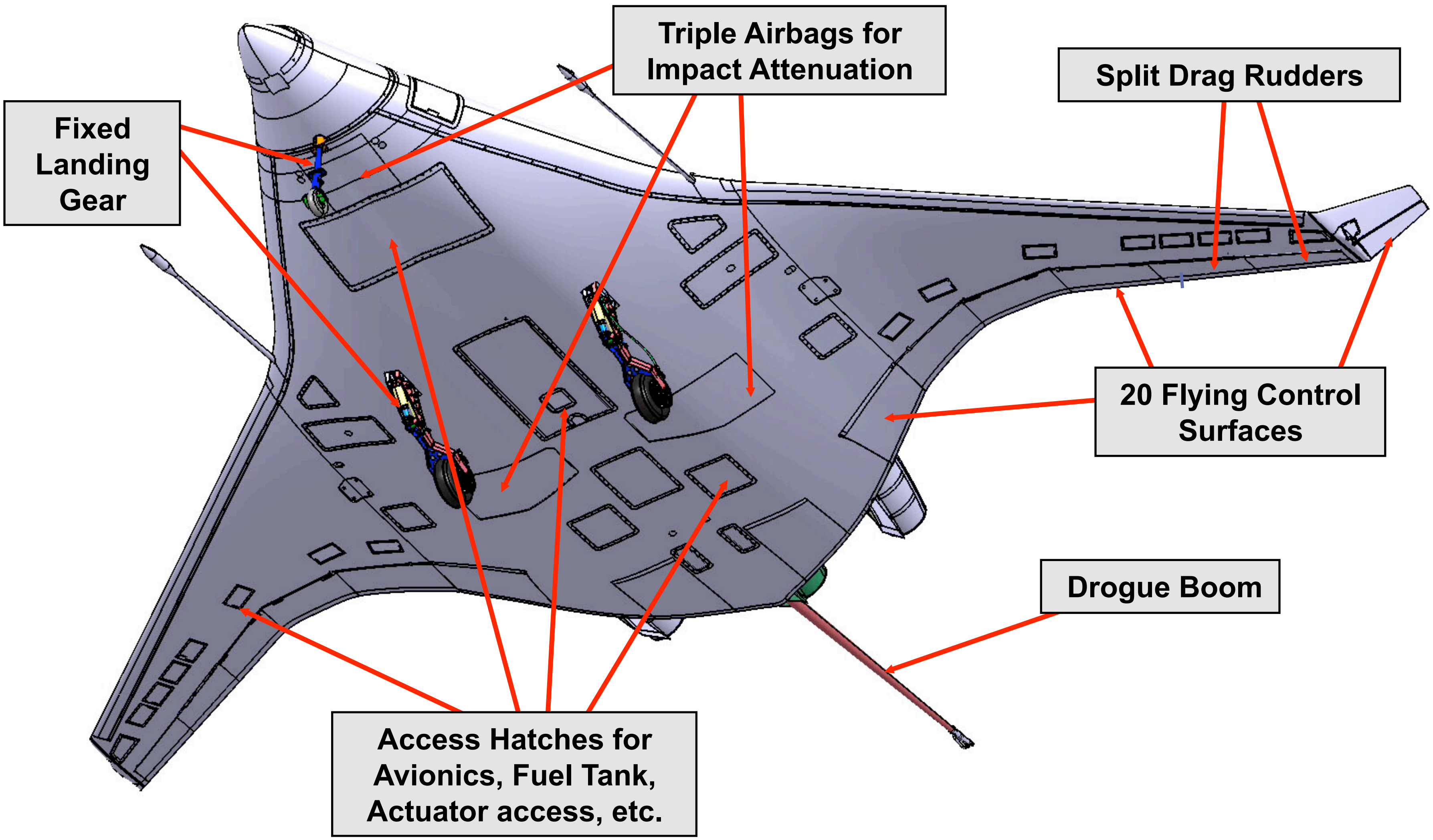
X-48B Configuration – Top View



X-48B Configuration – Internal View



X-48B Configuration – Underside View



Ground Control Station – Trailer

X-48B Flight Research Summary - I

- Twenty Flights completed in Blocks 1 & 2 (Basic Envelope Expansion)
  - 11 Flights w/ Slats Extended
    - Slats result in lower speeds and higher lift
  - 9 Flights w/ Slats Retracted
    - New Flight Control Laws / “1st Flight”
    - Envelope Expansion to Max Speed

- Fourteen Flights completed in Block 3 (Initial High-Alpha Envelope Expansion)
  - All 14 Flights w/ Slats Extended
  - Forward and Mid CG Locations

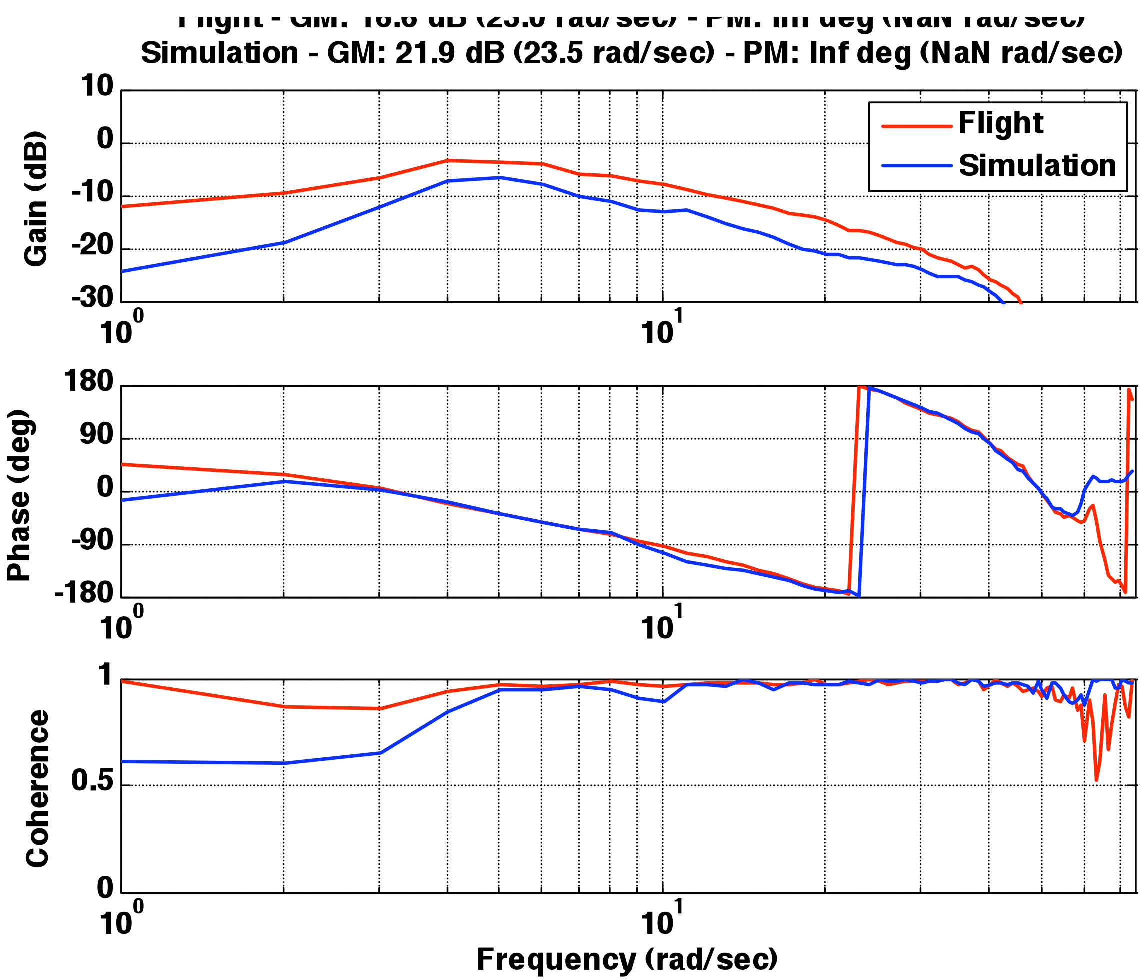
X-48B Flight Research Summary - II

- Sixteen Flights completed in Block 4 thus far (High-Alpha/ Stall Assessments)
  - Slats Extended & Retracted
  - Forward and Mid CG Locations
  - Relaxed Alpha Limiter
- Highlights:
  - Test Maneuvers
    - Real-Time Stability Margins
    - Automated Parameter Identifications (PID) – Freq Sweeps/Doublets
    - Steady Heading Sideslips - Simulate Cross-wind landings
    - Low approaches and go-arounds for ground effects assessments
    - Lazy-8s and Wind-up Turns
    - AOA Build-up Maneuvers approaching $C_l max$
    - Flight Characteristics at Stall Boundaries

Real Time Stability Margin (RTSM)

- In-Flight Stability has a long history at NASA Dryden Flight Research Center
  - Application to a wide variety of flight programs
    X-29, X-36, X-43, X-45, NF-15B 837
  - Method is motivated by inability to break loops on unstable aircraft
- Proprietary dynamic inversion based flight control
  - Numerous options for on-board excitations
- Excitation parameters and command sent via telecommand from GCS
  - Selectable injection points
  - Selectable waveforms
  - Selectable magnitudes

RTSM Results



From: Regan, Christopher, "In-Flight Stability Analysis of the X-48B Aircraft," AIAA Paper AIAA-2008-6571,AIAA Atmospheric Flight Mechanics Conference and Exhibit, Honolulu, Hawaii, Aug. 18-21, 2008.

X-48B Initial Flight Research Results

- Extremely maneuverable in roll
- Stable in pitch at all CG locations, very stable in yaw
- Aircraft very closely matches simulator for up/away flight (and landing)
- Stall AOA matches wind tunnel measurements within 1 degree
- Control system modeling generally matches actual flight behavior in the regions examined

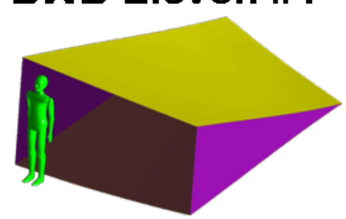
- Flight control design very robust – engine failures transparent to pilots
- Overall, the aircraft flies extremely well

X-48B What's Next for the Future

- Current plan to finish 40+ flights in CY2009
  - Follow-on Testing planned to continue thru FY2010
- Complete Phase 4 :
  - Stalls / High Alpha / Engine Out Assessments
- Phase 5/6:
  - Departure Resistance - Limiter Assaults / High Beta
- Potential new Engine Design
  - More Efficient = More Duration
- Low Noise Modifications (X-48C)
- Single Control Surface Aerodynamic Effects Measurements
- Intelligent/Adaptive Flight Controls – Gust Alleviation
- Larger Demonstrator Aircraft ???

The Vision

BWB Elevon #1



Considerations for Future Instrumentation

- Problem: large, flexible composite structures and low wing loading
  - Need real-time gust load sensing and alleviation technology
    - Wing shape sensing, control surface shape sensing
    - Embedded stress/strain measurements
    - Non-circular pressure vessel stress concentration monitoring
- Highly integrated propulsion system
  - Extensive/distributed total pressure measurements to assess boundary layer ingestion effects
  - In-flight thrust measurement would be highly desirable

Questions?